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Advances in autonomy for small UGVs

SPIE Defense and Security Symposium
Conference on Unmanned Ground Vehicle Technology VII
March 31, 2005

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Discussions

- Project Background
- Other Related Work
- Sensor Development
- Obstacle Avoidance
- Simulation
- Vehicle Implementation
- Conclusions

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Background

- Small UGVs are playing an increasingly important role in the military
  - Hundreds of EOD small robot systems in Iraq and Afghanistan
  - Only used in very specific scenarios that pose a serious risk to life and where the area is relatively secure
- All of the small UGVs currently in theater are strictly tele-operated
  - Requires the operator's full attention

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Background
The Robotic System

- The Urban Robot (URBOT) was designed for the Army in 2000 to perform reconnaissance of tunnels and sewers
- Originally only tele-operated with digital video and audio
- In 2002 a non-differential waypoint navigation capability was added
- PC based OCU developed for route planning - MOCU

Project Purpose

- Small UGVs must be more autonomous to become more useful in tactical situations
  - We need to relieve the operator from the burden of constant control
- Obstacle avoidance is the corner stone of an autonomous UGV
  - Required for any advanced behaviors
- Obstacle detection sensors for small UGVs pose a significant challenge
  - Sensor must be practical for tactical small UGVs (no SICK lasers, no Sharp IR sensors, no Polaroid ultrasonic sensors)

Project Goal

- Find or develop obstacle detection sensors that are truly practically for small UGVs
  - Small
  - Low-power
  - Light-weight
- Demonstrate the level of autonomy that can be achieved with those sensors
  - Robust obstacle avoidance

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Related Work

- Only programs focused on tactical small UGVs with practical sensor systems considered
  - Lots of research on behaviors using research platforms, much of it indoors in laboratories
- DARPA Tactical Mobile Robot (TMR) program
  - Goal was to develop autonomy in urban environments with minimal human interventions (<1 command per 50 meters)
- TACOM Wayfarer and Sentinel programs
  - Demonstrate autonomous urban reconnaissance

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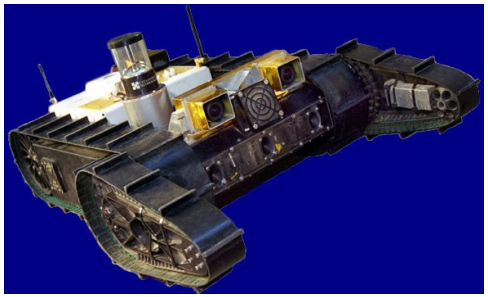
Related Work - TMR

- TMR JPL Urbie – Stereovision ODOA
  - 1998 - 2002
  - 80x60 pixel disparity maps
  - 233MHz PII PC/104
  - OD algorithm applied directly to disparity maps
    - No obstacle, traversable obstacle, non-traversable obstacle
  - Used variant of Carnegie Mellon University (CMU) Morphin algorithm for obstacle avoidance
  - Demonstrated reasonable ODOA in outdoor environments
    - System, including PC104 stack too large for a Packbot



Related Work - Wayfarer

- TACOM Wayfarer and Sentinel programs
  - iRobot Packbot with laser, stereovision and INS
    - 360° SICK LADAR and Point Grey Bumble Bee stereo system
  - Working on ODOA, street following, map construction, video and audio recording and more
  - Demonstrated good progress in autonomy for small UGVs
  - Sensors still not practical for a tactical small UGVs
    - FCS SUGV will be 25% smaller than a Packbot

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Sensor Development

- JPL Smart Cameras
  - Multi-year, joint effort between JPL and SSC San Diego
    - Leveraged DARPA MAV funding
  - All-in-one miniature vision system (2 inches square)
    - On-board imaging and stereo/OD processing
    - 640x480 Kodak CMOS imager
    - Xilinx VertexII FPGA
    - Motorola Starcore DSP
    - NTSC output for debugging
  - Master-slave configuration for stereovision
    - Boards communicate via a high speed serial bus

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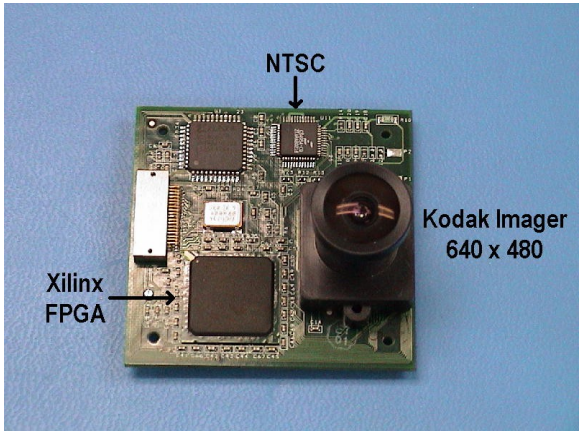
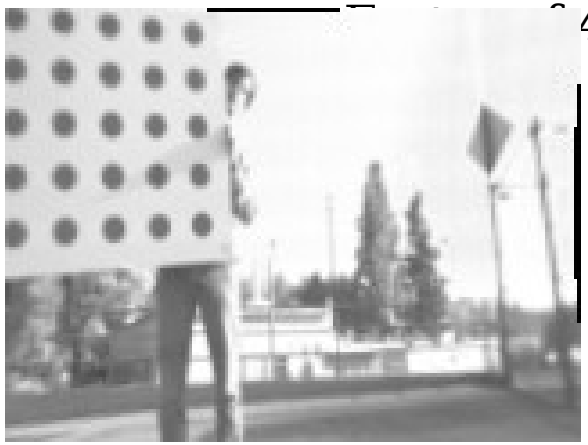
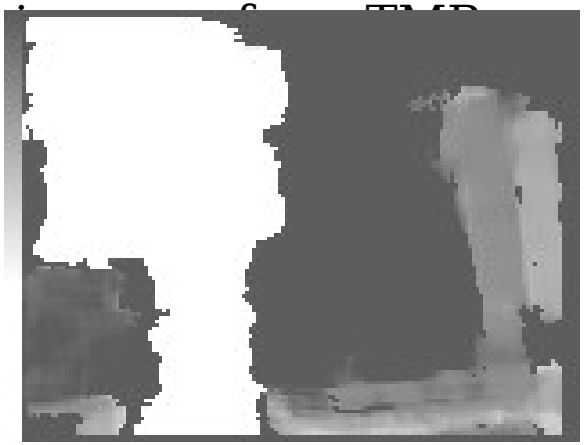
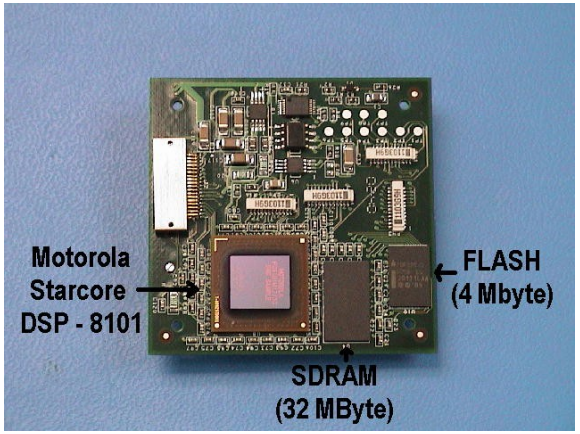
Sensor Development

- JPL Smart Cameras
  - FPGA interfaces directly to imager and performs some preprocessing
  - DSP running scaled down version of JPL's standard stereovision software
  - 160x120 pixel disparity maps



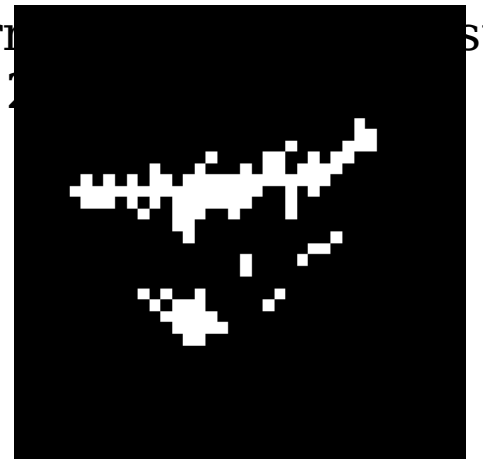






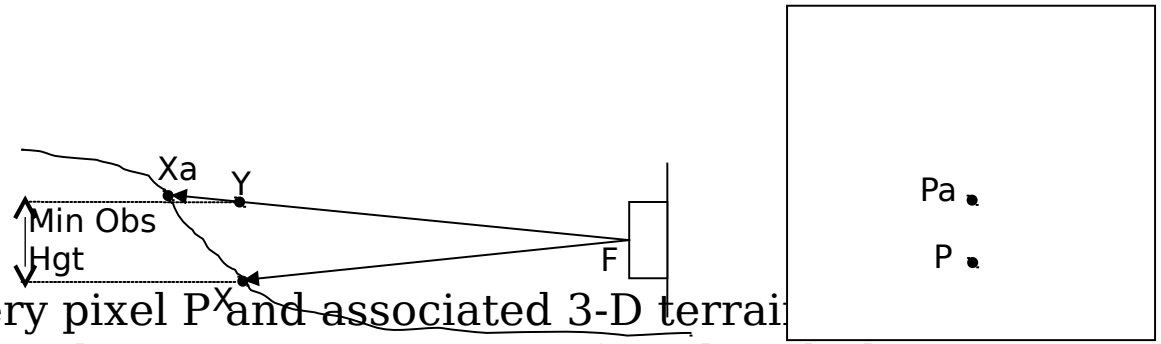
Sensor Development

- JPL Smart Cameras – Obstacle Detection
  - From disparity map, cameras compute a 2-D occupancy grid like obstacle map.
  - Obstacle map is output over a TTL serial line at approximately 2Hz
  - Map is 7x7m and consists of 41x41 cells (~17cm square)
  - Map is compiled as a portable gray map file (PGM)
    - A[illegible]orm[illegible]stacle pixel c[illegible]e 2



Sensor Development

- JPL Smart Cameras – Obstacle Detection Algorithm
  - OD algorithm effectively looks at the slope of the terrain



  - For every pixel P and associated 3-D terrain point Xa, a corresponding point in space Y is found such that it is “min obs hgt” above X. The pixel Pa is found based on Y and it’s associated terrain point Xa. If Xa is closer to the camera than X or if the slope from X to Xa exceeds the set threshold then P is considered to be an obstacle pixel. If the number of pixels in any 2-D obstacle map cell found to be obstacles exceeds a threshold that cell is marked as an obstacle

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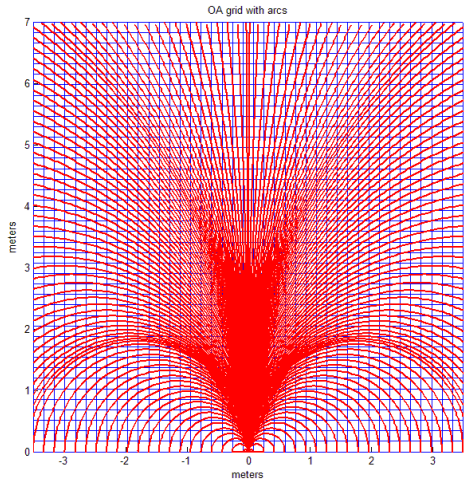
Obstacle Avoidance

- Loosely based on CMU Morphin algorithm and the Distributed Architecture for Mobile Navigation (DAMN)
  - Distributed behavior based system
    - Multiple behaviors vote on desired actions
    - Votes scaled from 1 to -1
  - Obstacle avoidance behaviors vote for or against a

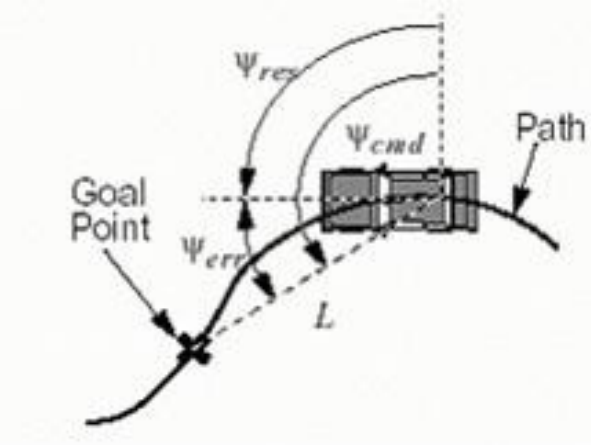
$$R = \frac{V}{\dot{\Theta}}$$

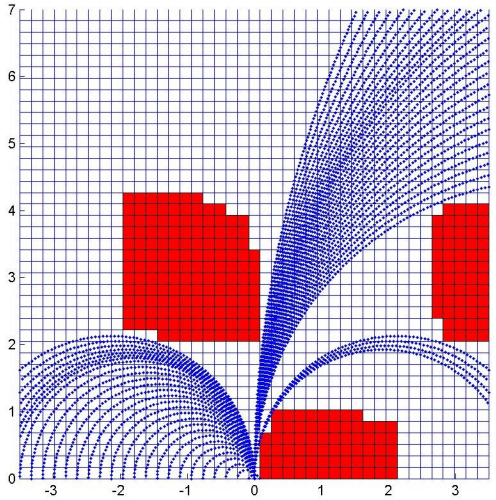
ed and turn rate



Obstacle Avoidance

- OA behavior votes against (0 to -1) arcs that are blocked
  - Vote is determined by the distance the vehicle could travel along that arc before it encounter





- Path following behavior votes for arcs (0 to 1) that are nearest the arc calculated by the waypoint navigation routine

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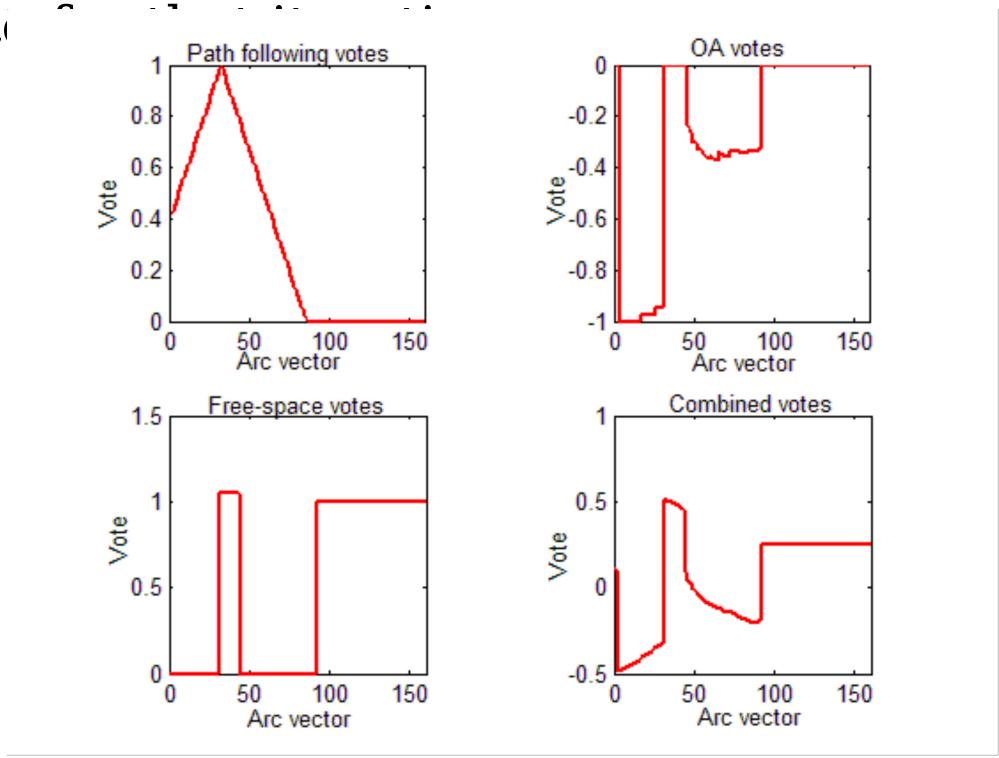
Obstacle Avoidance

- OA behaviors and arbiter
  - Arbiter combines weighted votes from all behaviors
  - Arc with highest vote is selected and used to set the velocity and turn rat



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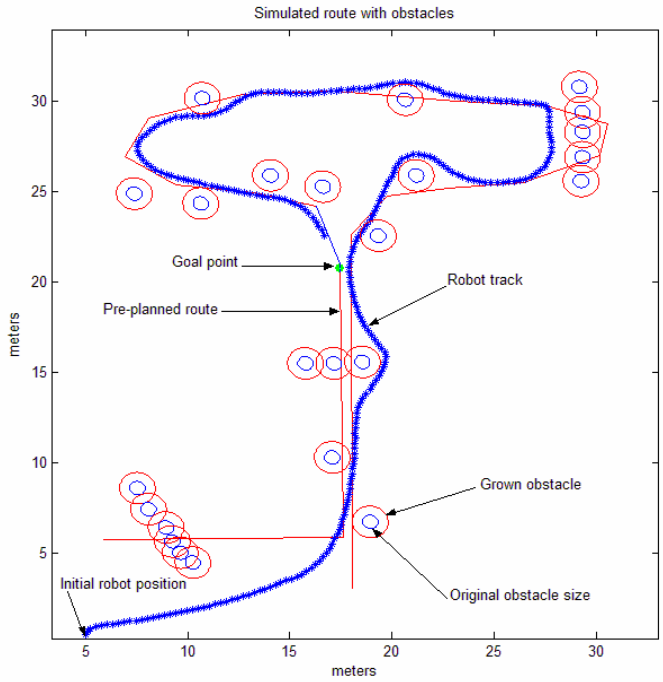
Simulation

- OA simulation in Matlab
  - Uses same URBOT simulator and route following code that was used to develop the waypoint navigation capability – fair degree of confidence it will transfer to the



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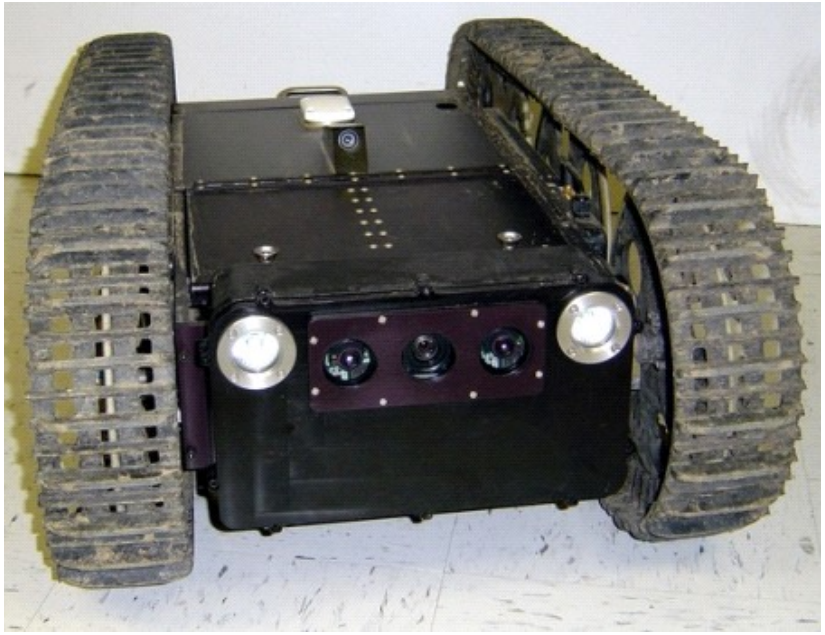
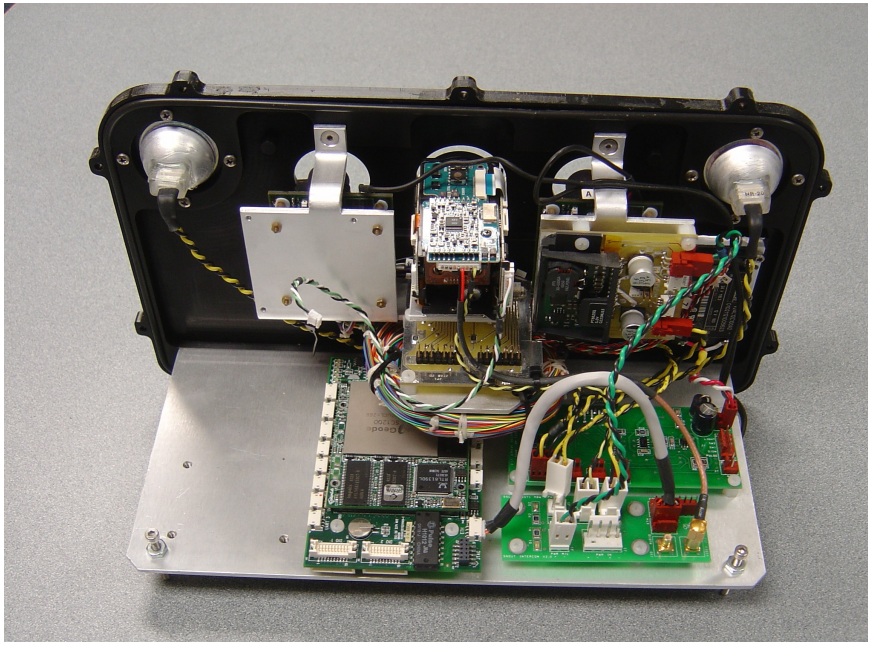
Vehicle Implementation

- New Snout developed to house stereo cameras
  - No tilt, front cover with attached electronics tray
  - Small Sony block camera between the stereo cameras
  - Headlights, eventually test stereovision with at night





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Conclusions

- Successfully developed a miniature stereovision system suitable for robust integration into a small UGV
- Preliminary data looks good – adequate OD with relatively little noise
- Poor quality optics make system difficult to calibrate
- Slow update rate (~2Hz) requires additional processing on robot – OA map dead reckoning
- Simulation and initial tests show OA algorithms are working well